LONG TERM TRENDS IN THE INTENSITY OF THE GALACTIC COSMIC RADIATION AND THE FREQUENCY OF OCCURRENCE OF SOLAR PARTICLE EVENTS

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With a great deal of data and/or help from J. Beer, G. Dreschhoff, F. McDonald, G. Raisbeck, M. Shea, D. Smart, F. Yiou, and E. Zeller.

THE MODERN EPOCH (1936- Present)

- **Ground Level, Balloon, and satellite measurements of the Galactic Cosmic Radiation, and solar particle events**

- **Correlations with solar phenomena**

- **Theoretical Understanding**

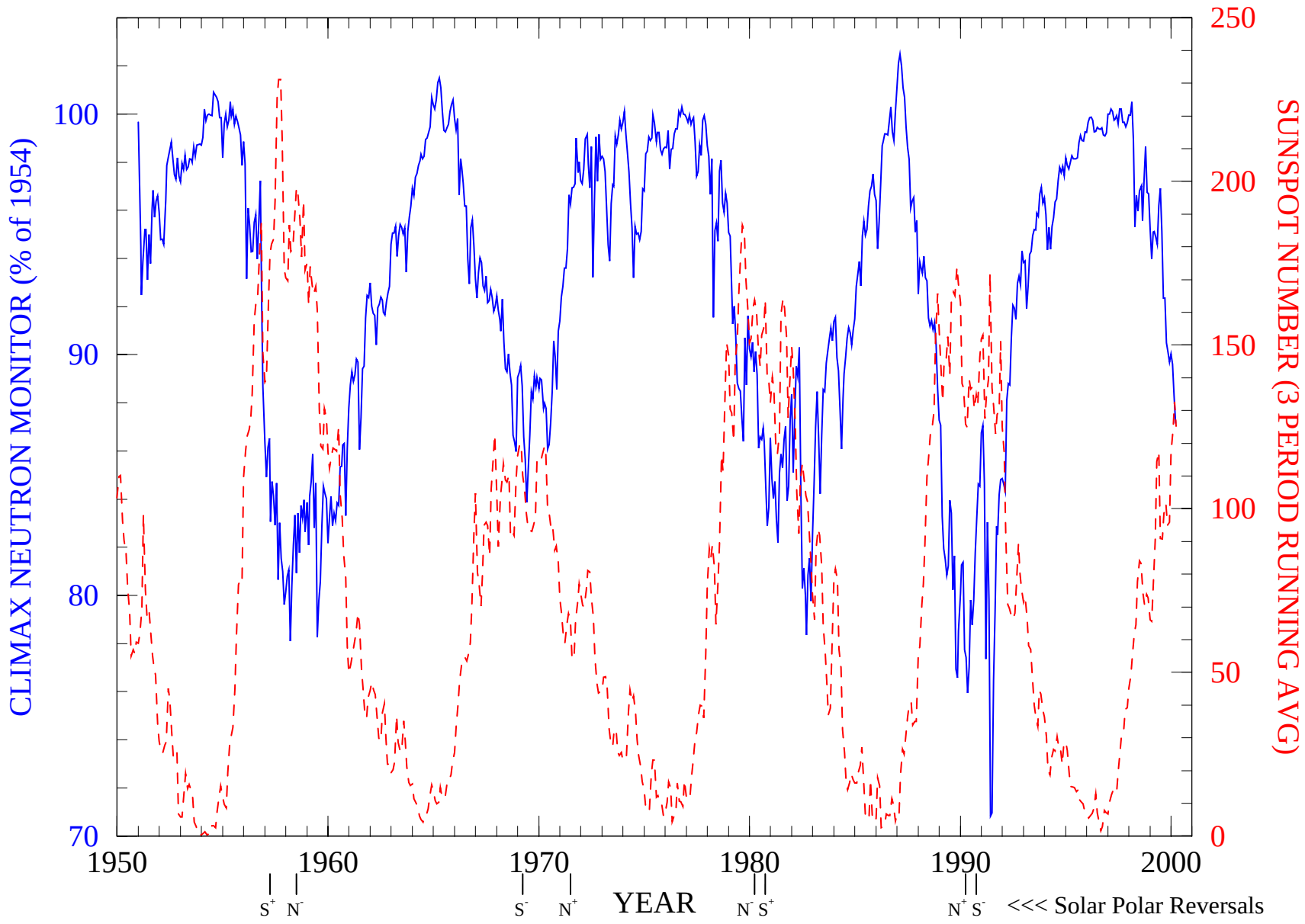
  - **The Parker CR Propagation Equation**
  - **Acceleration processes in shocks.**
  - **Nuclear and chemical processes in the atmosphere.**

EXTRAPOLATION TO THE PAST

- **A source of historic data: ICE CORES.**

- **For Galactic CR: 850-1978AD.**

- **For Solar Particle Events: 1572-1950 AD.**



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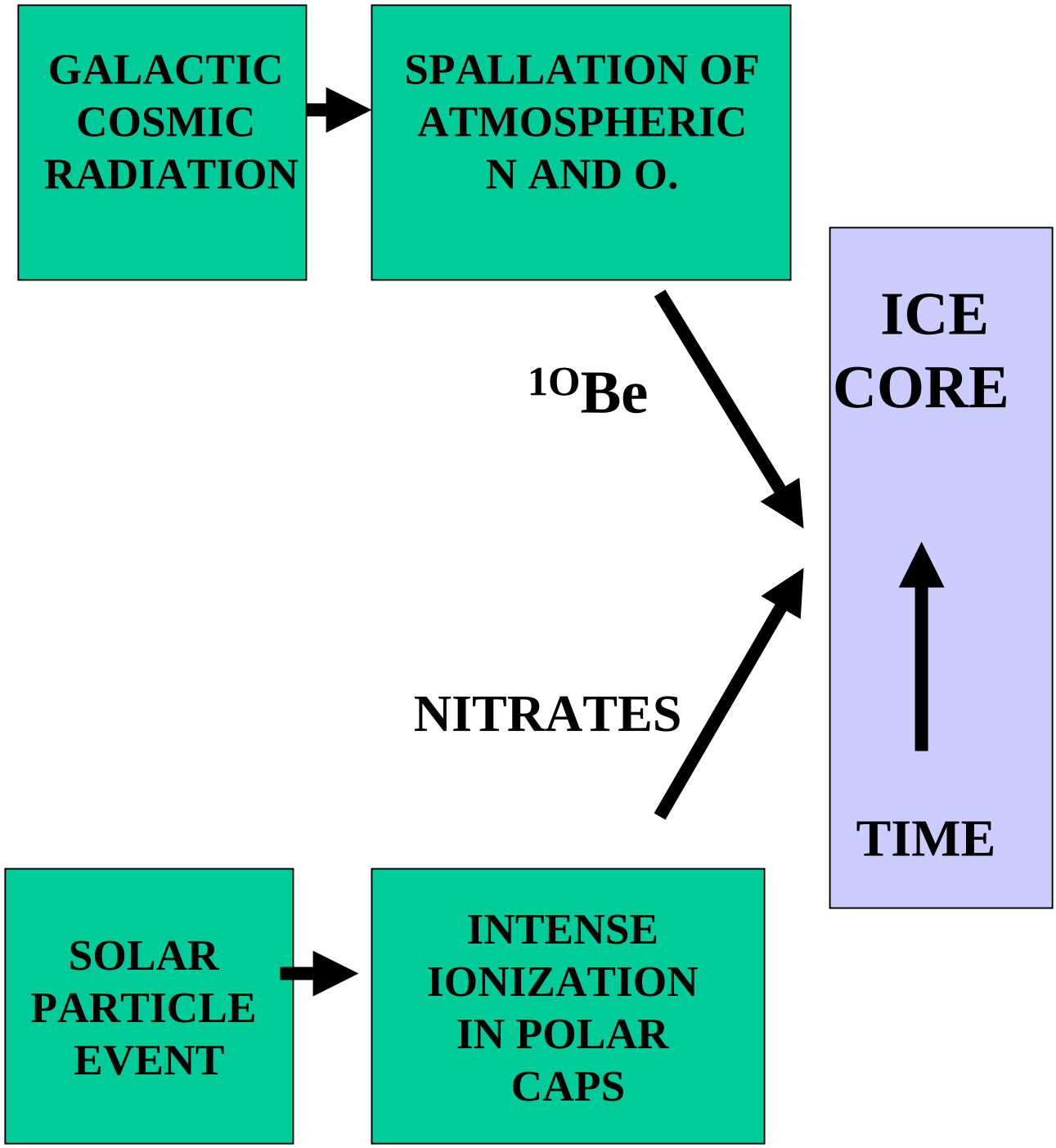
THE PALEO- COSMIC RADIATION RECORD



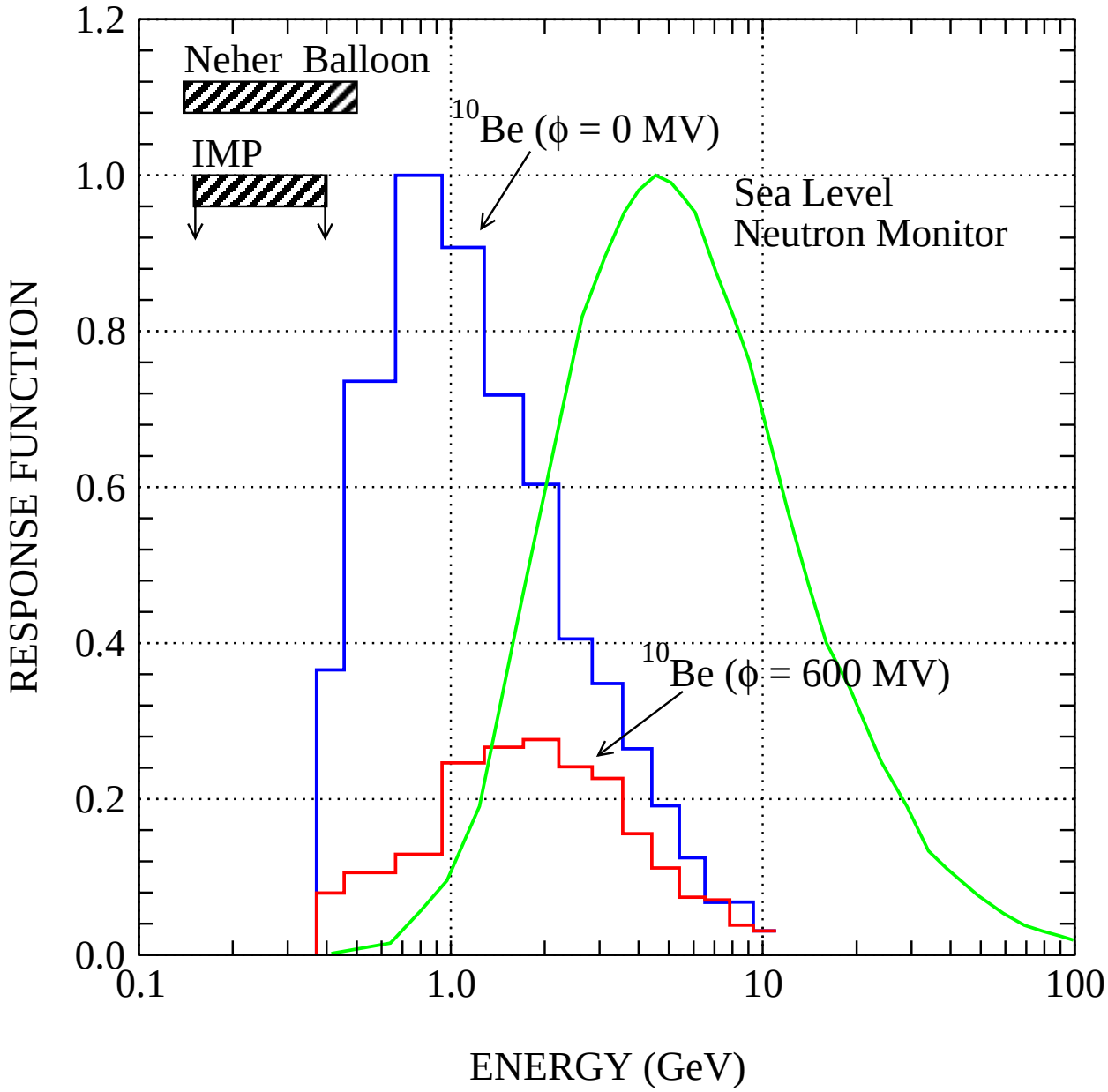
Cosmic Rays in the Atmosphere: Cosmogenic Radionuclides

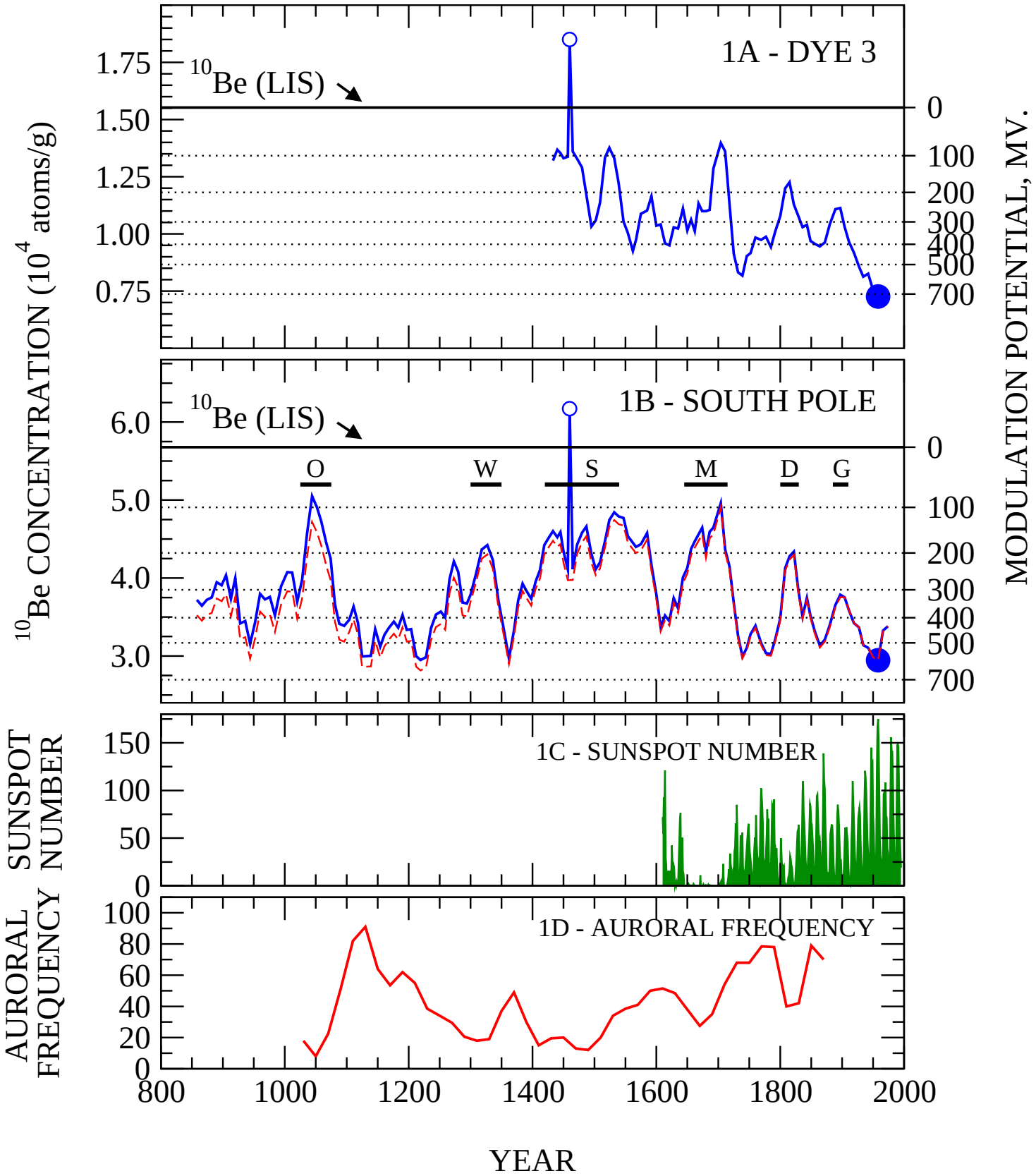
- ^{10}Be (half-life 1.5 x 10^6 years) produced by cosmic ray interactions in the atmosphere via spallation of atmospheric N and O.

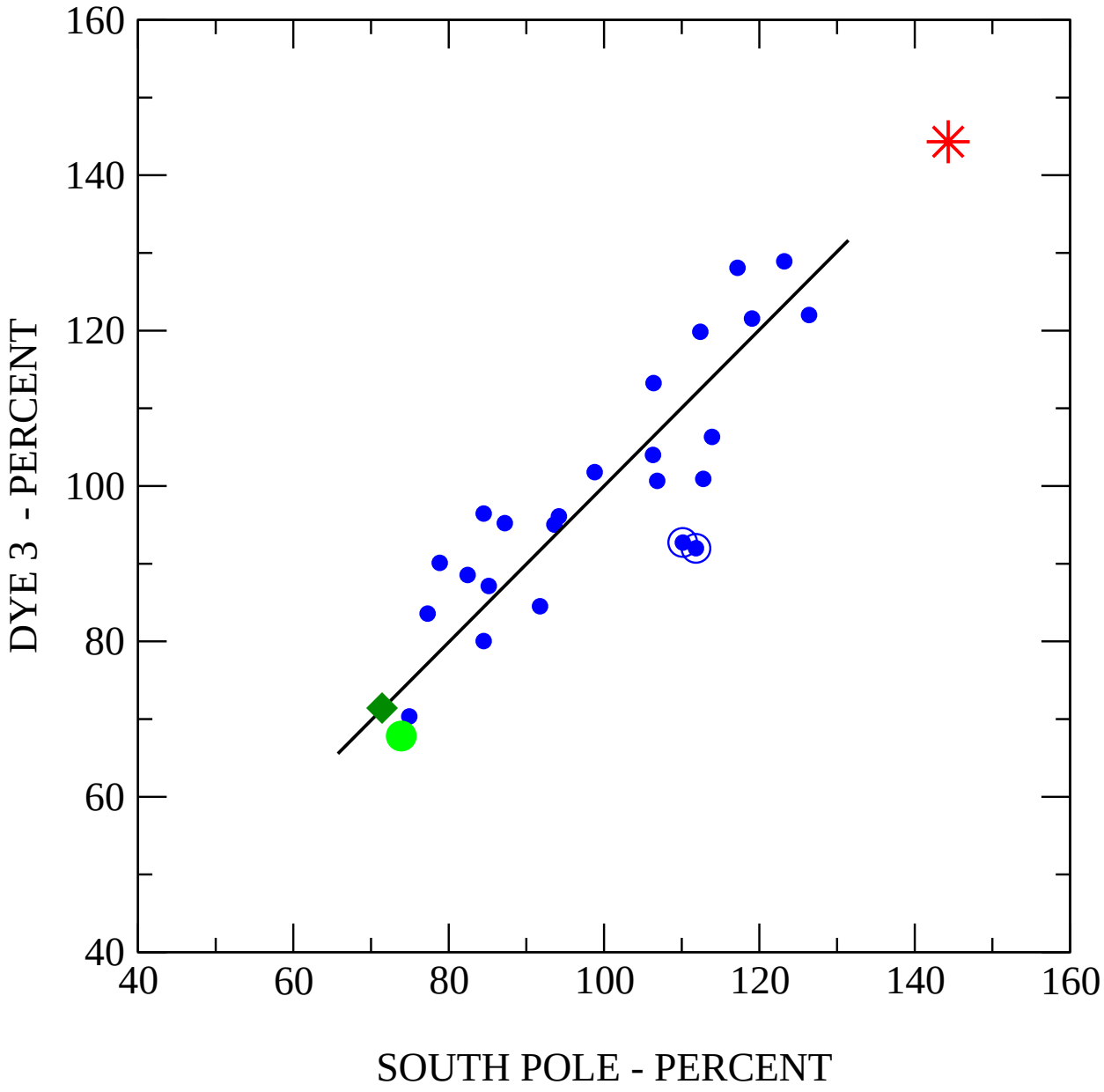
- The ^{10}Be atoms become attached to aerosols which are removed by precipitation on a time scale of ~1 year.

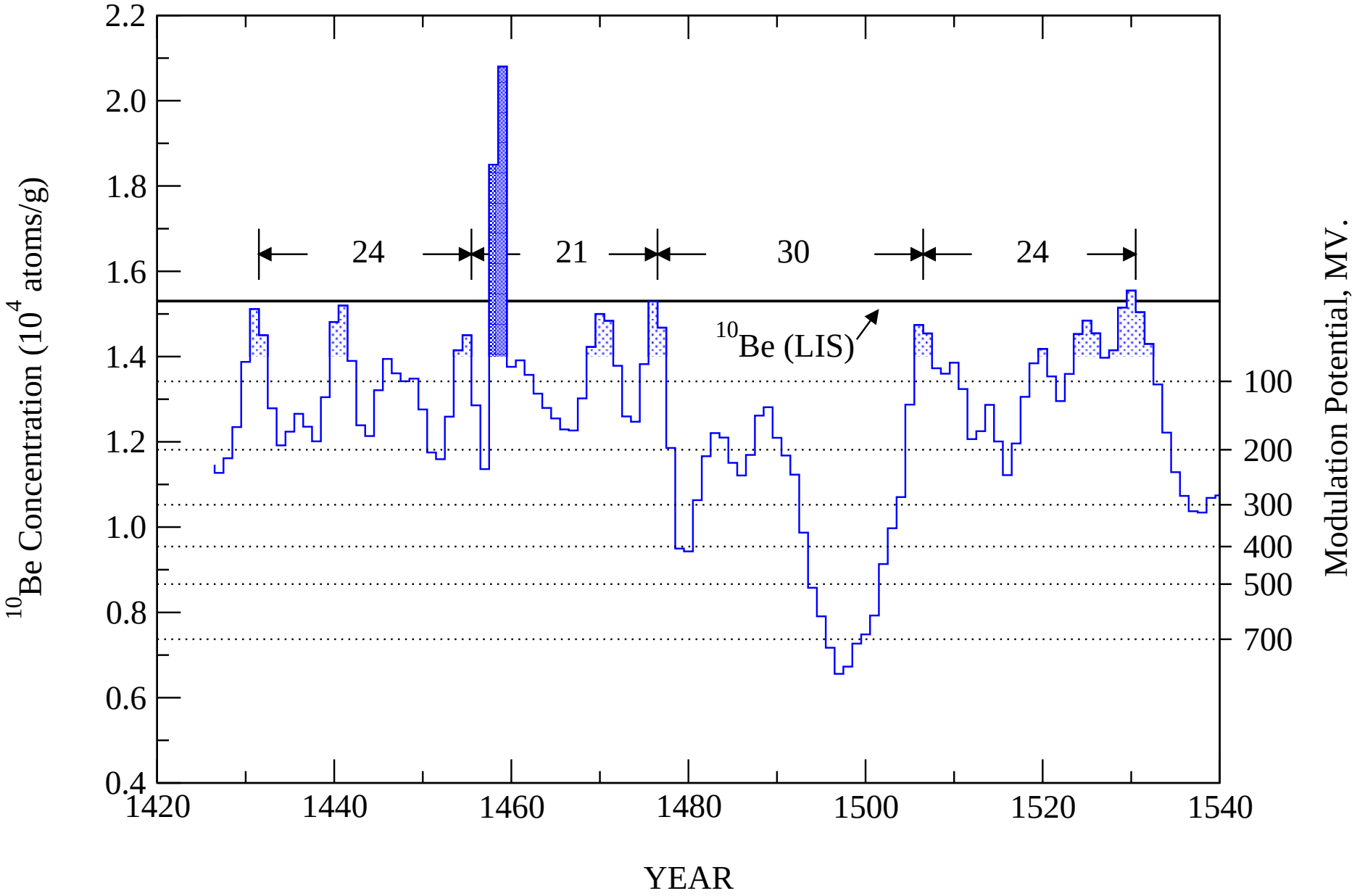
- In polar regions, these aerosols are incorporated into snow layers – compressed into ice. ^{10}Be records from ice cores make it possible to study cosmic ray history over periods > 10,000 years back in time.

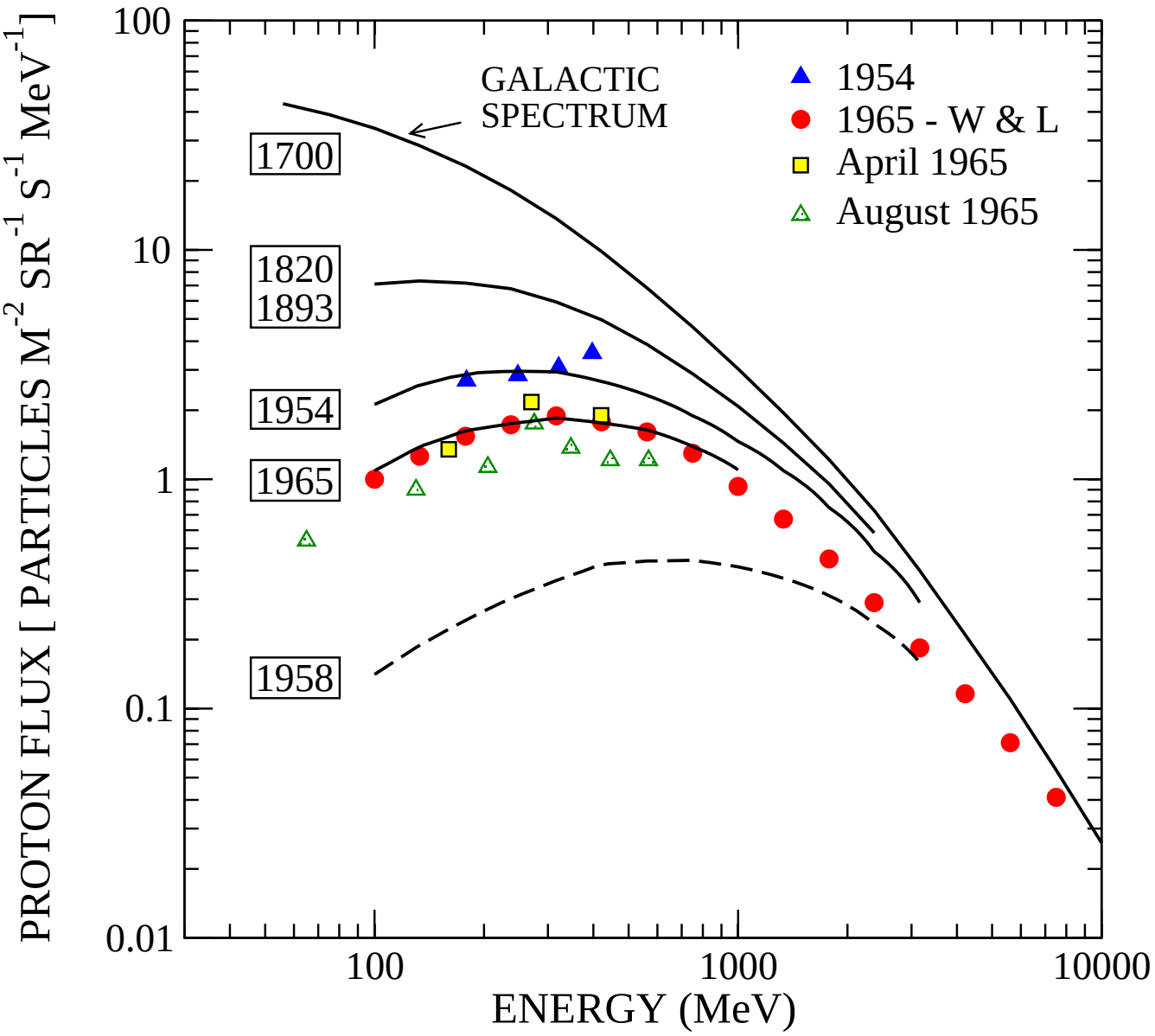
- The cosmogenic radionuclide flux from atmosphere $\rightarrow$ ice reflects the production rate as well as changes in the exchange rate between stratosphere and troposphere and in the scavenging process from the atmosphere [This can be a problem during climatically unstable periods].

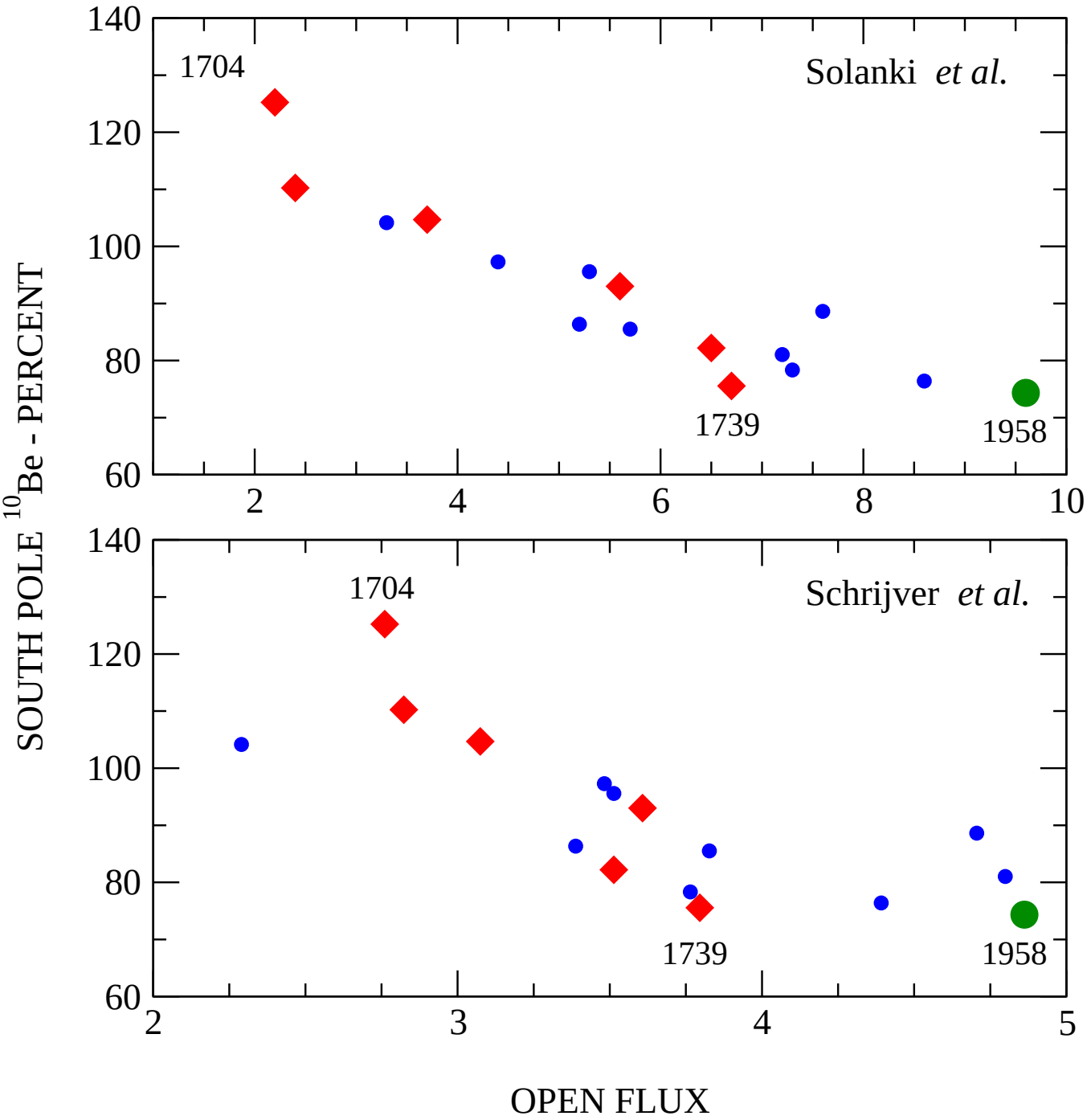

Neher Balloon
IMP
^{10}Be (ϕ = 0 MV)
Sea Level
Neutron Monitor
^{10}Be (ϕ = 600 MV)
RESPONSE FUNCTION
ENERGY (GeV)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0.1
1.0
10
100


1A - DYE 3
^{10}Be (LIS)
1.75
1.50
1.25
1.00
0.75
0
100
200
300
400
500
700
1B - SOUTH POLE
^{10}Be (LIS)
O
W
S
M
D
G
6.0
5.0
4.0
3.0
1C - SUNSPOT NUMBER
150
100
50
0
1D - AURORAL FREQUENCY
100
80
60
40
20
0
800
1000
1200
1400
1600
1800
2000
YEAR
^{10}Be CONCENTRATION (10^4 atoms/g)
MODULATION POTENTIAL, MV.
SUNSPOT NUMBER
AURORAL FREQUENCY


160
140
120
100
80
60
40
40
60
80
100
120
140
160
DYE 3 - PERCENT
SOUTH POLE - PERCENT


2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
^{10}Be Concentration (10^4 atoms/g)
24
21
30
24
^{10}Be (LIS)
100
200
300
400
500
700
Modulation Potential, MV.
1420
1440
1460
1480
1500
1520
1540
YEAR


PROTON FLUX [PARTICLES M-2 SR-1 S-1 MeV-1]
ENERGY (MeV)
100
10
1
0.1
0.01
100
1000
10000
GALACTIC
SPECTRUM
1700
1820
1893
1954
1965
1958
1954
1965 - W & L
April 1965
August 1965


140
120
100
80
60
1704
Solanki et al.
1739
1958
2
4
6
8
10
140
120
100
80
60
1704
Schrijver et al.
1739
1958
2
3
4
5
SOUTH POLE 10Be - PERCENT
OPEN FLUX

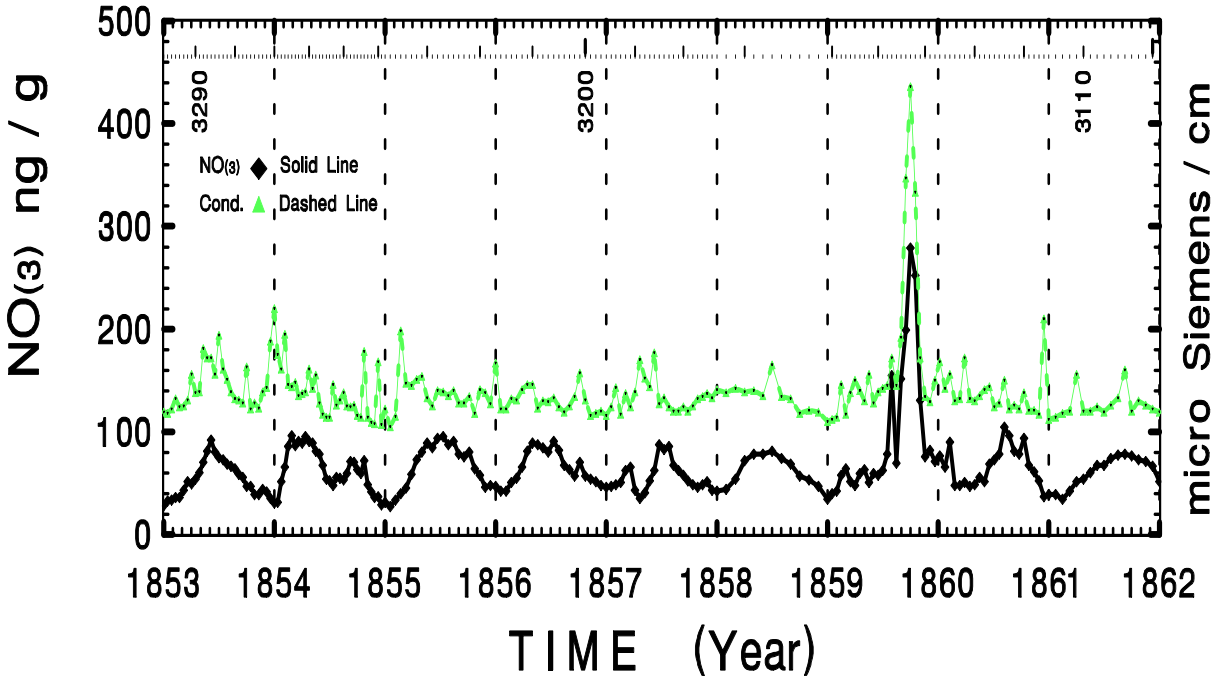


Figure 1.1. An example of the high-resolution nitrate and electrical conductivity data from a core after the firn is highly consolidated. The impulsive event at 1859.75 is the largest such event in the period 1561-1991 and occurs in close correlation to the 1 September 1859 “white light” flare seen by Carrington. The scale along the top of this and other presentations of the nitrate data gives the sample number in the data deposited with the World Data

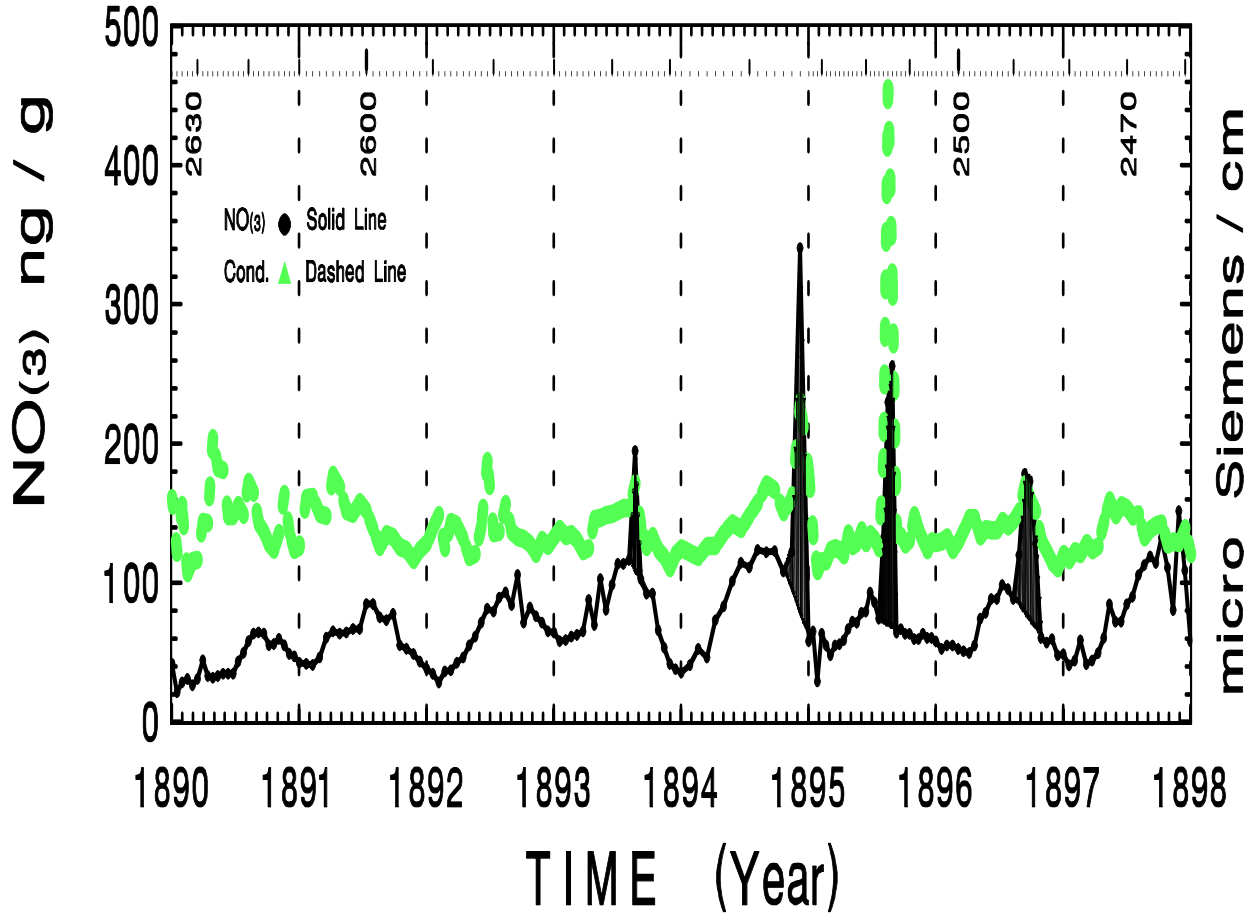


Figure 1.4A. The data from a section of the 13th Schwabe (11 year) cycle in which there is a number of large impulsive nitrate events. The impulsive nitrate events have been highlighted for clarity.

A SPECULATIVE MECHANISM FOR LONG TERM TRENDS IN THE GENERATION OF SPE BY A CME

PROPERTY	MODERN	1889	MAUNDER
CHROM0SPHERIC MAGNETIC FIELDS	1	0.5	0.3
ALFVEN VELOCITY	1	0.5	0.3
COMPRESSION RATIO	1	2	3.3
SPE INTENSITY (SEE NOTE)		GREATER	MUCH GREATER

NOTE: ASSUMING THE SAME CME VELOCITIES FOR ALL THREE CASES CONSIDERED.

VARIABILITY OF THE FREQUENCY OF OCCURRENCE SOLAR PARTICLE EVENTS OVER TIME[1]

SUNSPOT CYCLE	NUMBER OF SPE.	FLUENCE (x 10^9)
MODERN EPOCH (1954 - 1996)	0.75- 1.0	5.7
1889 - 1901	5	31.2
1700 - 1711	4	16.3

[1] NOTE- Based upon Solar Particle Events with 30 MeV fluences of $2x10^9$ per cm^2 and above.

CONCLUSIONS

IN THE MODERN ERA (Since 1954)

(1) THE GALACTIC COSMIC RAY INTENSITY NEAR EARTH HAS BEEN ONE OF THE LOWEST IN THE PAST 1150 YEARS.

(2) THE FREQUENCY OF OCCURRENCE OF LARGE SOLAR PARTICLE EVENTS HAS BEEN LOW COMPARED TO THE LONG TERM AVERAGE.

FOR A PERIOD SIMILAR TO 1889 - 1901

(3) THE GALACTIC COSMIC RAY INTENSITY WAS HIGHER COMPARED TO THE MODERN ERA BY FACTORS OF:

- **7.0 AT 100MeV**
- **3.5 AT 300MeV**
- **2.25 AT 1.0GeV.**

(4) THE FREQUENCY OF OCCURRENCE OF LARGE SPE WAS A FACTOR OF ~5 TIMES GREATER COMPARED TO THE MODERN ERA.

RESEARCH GOALS

GALACTIC COSMIC RADIATION

IMPROVE CROSS- CALIBRATION OF ^{10}Be AND . NEUTRON MONITOR DATA.

OBTAIN 1-2 YEAR RESOLUTION CORES TO INVESTIGATE 11-AND 22-YEAR CYCLE EFFECTS

OBTAIN IMPROVED ESTIMATES OF THE LOCAL INTERSTELLAR SPECTRUM OF THE GCR

USE ^{10}Be DATA TO IMPROVE KNOWLEDGE OF LONG TERM CHANGES IN COSMIC RAY MODULATION

SOLAR PARTICLE EVENTS

FURTHER VALIDATION- HIGH RESOLUTION CORES FROM ARCTIC AND ANTARCTIC

IMPROVE FLUENCE CALIBRATION

EXTENSION OF THE RECORD TO THE "GRAND MAXIMUM" (1100-1350AD) AND THE SPOERER MINIMUM (1420-1540AD)

DETAILED STUDY OF ASSOCIATION OF HIGHER SPE OCCURRENCE, AND LOWER SOLAR ACTIVITY FOR THE INTERVAL 1890-1910AD.